FRACTURE OF THE BASE OF THE SKULL.

A CONTRIBUTION BASED ON THE CLINICAL AND PATHOLOGICAL RECORDS OF FIFTY CASES.

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THIS study has received fresh impetus from the recent work of Rawling (*Lancet*, April 9, 16, 23, 1904), who devotes special attention to the course followed by lines of basal fracture, and gives certain rules which he states will in the great majority of cases be found to be correct, though exceptions may occur. The accompanying diagrams represent approximately the lines indicated by this author. (Fig. 1.)

Among other points of interest in Rawling's communication may be mentioned the following: The sella Turcica was implicated in 70 per cent. of cases; the line of fracture is extremely liable to follow a suture, either causing its separation or cutting across its irregularities; Battle's view that lines of fracture are apt to cease at foramina is erroneous, as well as the idea that the optic foramen is extremely liable to implication; profuse and persistent bleeding from the ear is sufficiently indicative of middle meningeal hæmorrhage to suggest operation over this artery without other sign of its rupture.

These views are in some ways diametrically opposed to those usually accepted; for example, the general consensus of opinion regarding the lines of fracture, apart from the statement that a few general directions are followed, is thus expressed in Dennis' "System of Surgery," "At all events, the majority of basal fractures follow no predetermined rule."

With the view of contributing a number of consecutive observations towards the settlement of this question, as well as of studying other points of interest, I have gone over the autopsy reports of fifty cases of basal fracture, through the

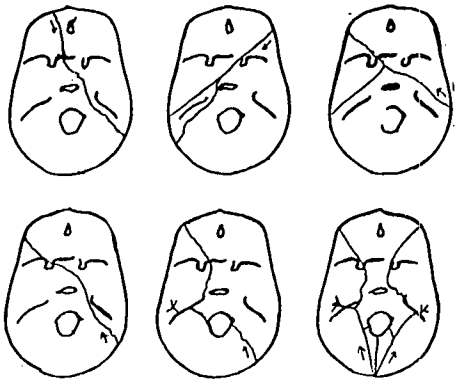

FIG. 1.—An approximate representation of Rawling's lines of fracture resulting from impacts of various directions.

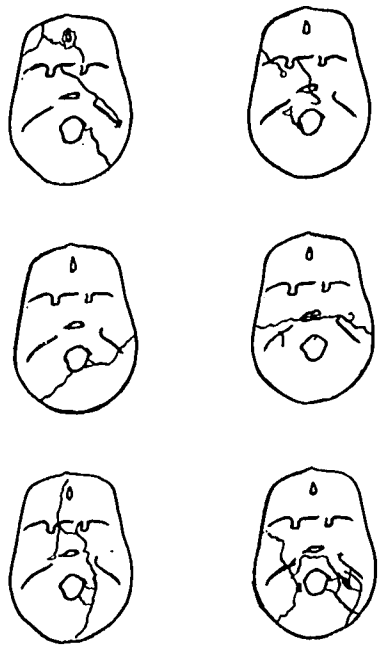

FIG. 2.—Approximate representation of von Wahl's bursting fractures as pictured in Dennis' "System of Surgery."

courtesy of Dr. Wright, pathologist at the Massachusetts General Hospital, and of Dr. Mallory, pathologist at the Boston City Hospital. Diagrams of all are submitted. It is not claimed that the exact course of each fracture is pictured, but the lines of fracture were in general so carefully recorded as to be susceptible of fairly accurate diagrammatic representation, excepting in minor particulars. In one case, that in which all the fossæ were invaded (Fig. 12), the statement was made that the fracture on the left was in the shape of a C, beginning in the occipital and ending in the orbital fossa, without indicating its exact course from one to the other; in this instance, therefore, the course of fracture should not be regarded as at all accurately represented except in its limits.

A word will be in place regarding the method of production of basal fracture. The view held by earlier writers that fractures of the base resulted from *contre-coup* was displaced by the irradiation theory of Aran (*Arch. gén. de Méd.*, 4th Series, T. vi, p. 180) (fortified by Hewitt, Bergmann, and others), who established the fact that in case of fracture resulting from a blow upon the vault the line of fracture tends to enter the nearest fossa, and that it is impossible experimentally to produce fracture by *contre-coup*. This view now generally obtains, with the modification that lines of least resistance are followed, as first suggested by Félizet, rather than the shortest anatomical route as maintained by Aran. The so-called bursting fracture of Hare (*Lancet*, February 4, 1888), Messerer, Hermann, and von Wahl presupposes a pressure upon the side of the skull producing a fracture of the base, much as pressure on the opposite poles of a spherical body causes it to burst across its equator. (Fig. 2.)

Rawling explains the so-called bursting fractures at the base by a modification of the irradiation theory. According to his view, if a man receives a violent impact on the back of the head, the force, though greatest at the point of impact, may be insufficient to overcome the resistance of the occipital bone in this region, and yet, when transmitted to the more delicate bones of the base, prove sufficient to cause their fracture.

Probably both these principles come into play upon the complicated structures of the skull under the various conditions of impact against bodies of various sizes and shapes. A few primitive experiments will serve to show that the question is not simple even when applied to fairly uniform bodies subjected to various forms of trauma.

If an orange is squeezed between the palms until it gives way, the crack appears across the equatorial line midway between the hands, and extends in both directions. This result is constant in whatever position the orange is held, thus eliminating, or even overcoming, the influence of grain. (Figs. 3 and 4.) This illustrates the bursting fracture. If, however, the orange is suspended in the air, or laid upon the table and struck a violent blow on one side with a stick, it breaks at the point of impact and shows no evidence of bursting force; again, if a watermelon is laid on the ground and struck on its side, it gives way at the point of impact, and a crack extends from this point in the same direction. In other words, the region last to give way under steady compression between two forces is the first to give way under a blow.

If, now, instead of suspending the orange we impale it upon a stick, thus weakening one portion of the rind, and strike its side upon the floor, a crack is likely to appear at the point where the rind is perforated by the stick. This might suggest force transmitted from the point of impact to the weakest part rather than bursting force; but if we drop an orange to the ground, a bursting crack is apt to appear at the equatorial line, or between the point of impact and the equatorial line, on one or both sides, without fracture at the point of impact; or again, if we drop a watermelon to the ground, a crack, suggestive of bursting force, appears across its equator as well as depression of the region of impact and radiating cracks about this region. In the case of the watermelon the crack tends to go around the end, apparently the line of least resistance. A tendency to bursting fracture is present then, when the body, after swiftly moving, is suddenly brought to a standstill, though no such tendency appeared when it was hang-

FIG. 3.—Simple illustration of bursting fracture.

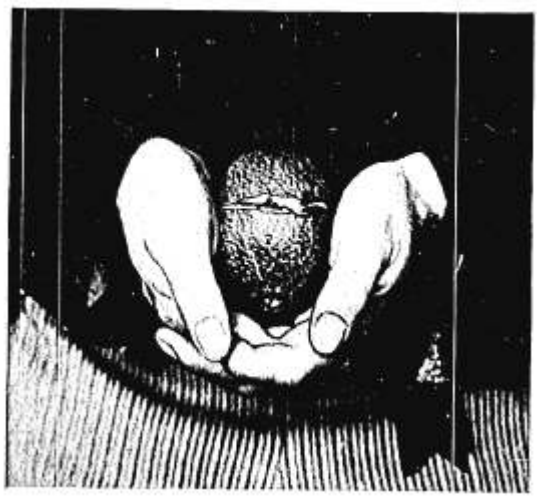

FIG. 4.—Simple illustration of bursting fracture.

ing quietly, and the implement of trauma was moving swiftly. This is doubtless because the momentum of the falling body causes its upper portion to act as a counter-compressant. The bursting principle, as well as the principle of transmitted force, may, then, have played a part in the case of the orange impaled upon the stick and struck upon the floor.

These simple experiments suggest that it is important to distinguish between falls on the head and blows upon the head from weapons, as well as to distinguish between both these conditions and a gradual pressure upon both sides of the skull.

These experiments, though suggestive, are introduced not with an idea that the structure of the skull and the conditions of actual trauma are even approximated, but with a view of illustrating the difficulties of the question with regard to objects of simplest structure subjected to the simplest forms of trauma, and to warn against too readily accepting any single explanation for the complex conditions found in basal fracture.

The following case, for which I am indebted to Dr. Wolberg, tends to show that even when compression occurs, if we have at the same time to do with a sharp blow from one of the compressing surfaces, especially if this surface offers a projection, the signs of greatest violence may occur at the point of impact. It also introduces another factor, namely, the age of the individual.

CASE.—A boy of about twelve jumped upon a rapidly moving hand-car. His head was caught between the cross-bar of the working-beam and the edge, or corner, of a tool-box. The result was a depressed fracture of the frontal bone, which rested on the tool-box.

Experiments on the cadaver promise little towards solving this problem. The question in dispute is not what occurs when the skull is subjected to violence, but what mechanical principles underlie the phenomena, of which we have already more evidence than we can analyze. Perhaps the following would be a reasonable working hypothesis: When the trauma results from (1) pure compression, the bursting principle alone, or at

least predominantly, underlies the fracture; (2) from a sharp blow, the violence is greatest at the point of impact and the transmission principle predominates; (3) from a fall, both factors take part. Between these three forms of trauma, *i.e.*, compression, blow, and fall, many gradations may occur, complicated still further by the character of the object causing impact and the age of the individual.

Possibly the addition of bursting force to the danger may partly explain the prevalence of falls over blows in the etiology of basal fracture, as illustrated by Graf's cases, in which sixty-three out of ninety resulted from falls.

FIFTY CASES.

The study of these fifty cases confirms the statement of Rawling that the impact is oftenest received in the basal plane, whether on the frontal or occipital region or upon the side of the head. There was no suggestion of the *contre-coup* of early writers. In fact, in the four cases resulting from blows on the vertex the line of fracture was continuous from the vertex to the base. When the line of fracture extended from any part of the vault, it generally entered the nearest fossa and extended in the direction of the force applied.

In twenty-two of the fifty cases, as will be seen from the appended diagrams, the lines of fracture either followed or suggested the lines of Rawling, as well as von Wahl's lines of bursting force, and fall almost invariably between the natural buttresses of the skull, indicated by various anatomists, extending from the vault to the base in the mid-frontal, external angular, mastoid, and occipital regions.

These results tend, therefore, to support the statement that basal fractures are prone to follow lines of least resistance.

The diagrams of the other twenty-eight cases, however, show results so variable as to make it plain that the exceptions to Rawling's lines, far from being occasional, are in the majority.

The sella Turcica was found a frequent seat of fracture, being implicated in eighteen cases (36 per cent.) from force

applied in all directions. The petro-occipital and masto-occipital sutures were also frequently involved, oftenest from violence in the mastoid region. The petrous portion of the temporal bone furnished a very frequent seat for fracture, generally in the transverse direction through the region occupied by the aural mechanism. This bone was fractured transversely twelve times, longitudinally four times. There was no example of the fracture, described by Rawling as a common form of middle fossa fracture, running through the external auditory canal on its way to the sphenoidal sinus, though there were several in which the fracture ran parallel with and anterior to the petrous portion. Nor was there corroboration of the observations of Honel (quoted by Dennis), that in seventeen out of the twenty-one cases of transverse fracture from blows on the side of the head the petrous portion was traversed longitudinally.

The orbital fossa was fractured in fourteen cases, five times from direct frontal violence, eight times from external angular or temporal violence, once from mastoid violence, in no case from occipital violence. The occipital fossa was implicated sixteen times, twice from frontal violence; the middle fossa ten times. There were seven instances (14 per cent.) of fracture limited to the base, two following blows on the vault in the horizontal plane, and two from unknown violence. In the five cases in which the direction of the violence was known, the line of fracture was generally in the same direction.

Comparisons of frequency of fossa implication with the records of Hewitt and Bergmann are as follows:

Anterior fossa alone, 0 per cent.; Hewitt and Bergmann, 12 per cent.
Middle fossa alone, 20 per cent.; Hewitt and Bergmann, 43 per cent.
Occipital fossa alone, 16 per cent.; Hewitt and Bergmann, 15 per cent.
Two or more fossæ, 64 per cent.; Hewitt and Bergmann, 30 per cent.

In studying these records, one finding impressed itself upon me which, so far as I am aware, has not been specially noted, namely, the frequent disintegration of brain tissue on the under surface of the frontal lobes posteriorly, and the under surface of the temporosphenoidal lobes anteriorly, that is, the

region bordering on the fissure of Sylvius. (Fig. 5.) This can only be due, it seems to me, to the impact of these regions against the lesser wing of the sphenoid bone, which fits into the fissure of Sylvius and separates these lobes.

Subconjunctival hæmorrhage led in one case to a diagnosis of basal fracture, not confirmed by autopsy. This will serve to remind us that subconjunctival hæmorrhage is not an infallible sign of fracture other than fracture of the outer wall of the orbit.

Regarding the direction of the blow in these instances, the only data to guide me were the statements of witnesses found in the clinical records, and the marks of external violence as recorded either in the clinical or the post-mortem records, or both. It is not claimed, therefore, that the conclusion arrived at regarding the direction of the blow was in all cases accurate; in fact, it is manifestly difficult and often impossible to determine the exact direction in which the skull receives the impact, even though the seat of the blow may be easily approximated. The appearance of various contusions in the same case may even prevent deciding upon the seat of the violence which caused the fracture. I was surprised to find several cases in which it was recorded that no external sign was found either by the clinical or the pathological examiner. There is a prevailing impression that this state of affairs is very rare, and results only from the use of some such instrument as the sand-bag.

The study of the cases in which the direction of the violence was known, together with that of other cases on record, enables us to judge the probable direction in the other cases, for it seems that the general direction of the fracture is that of the violence. This knowledge may prove of assistance in medicolegal inquiry, even though its clinical application may be limited.

In eleven cases the line of fracture was definitely stated to cease at a foramen; those mentioned were the foramen magnum, the jugular foramen, the foramen rotundum, the foramen ovale, the foramen spinosum, and the anterior condyloid foramen.

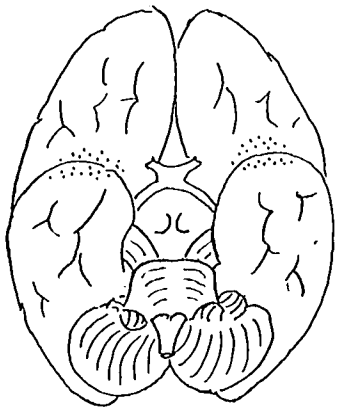

FIG. 5.—The dots show region of frequent disintegration of brain substance, due probably to impact against wing of sphenoid bone.

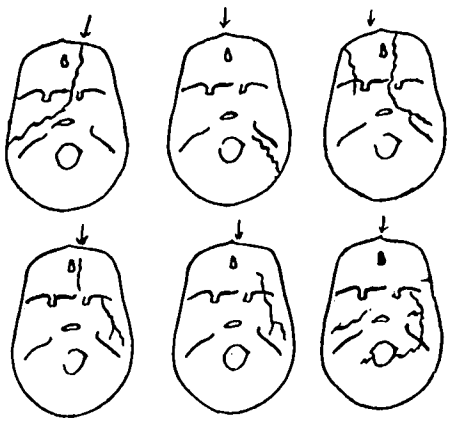

FIG. 6.—Lines of fracture resulting from frontal violence.

FIG. 7.—Lines of fracture resulting from violence in region of external angular process of frontal bone.

FIG. 8.—Lines of fracture resulting from violence in mastoid region.

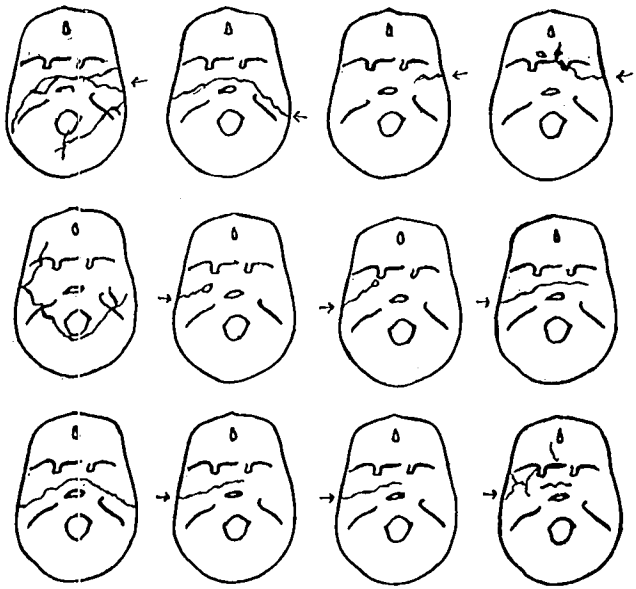

FIG. 9.—Lines of fracture resulting from lateral violence.

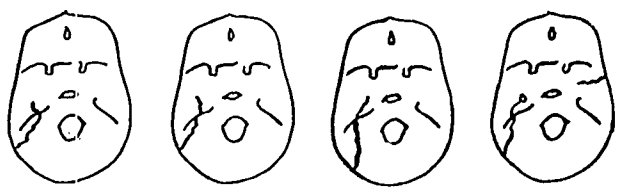

FIG. 10.—Lines of fracture resulting from blows in median line of vault.

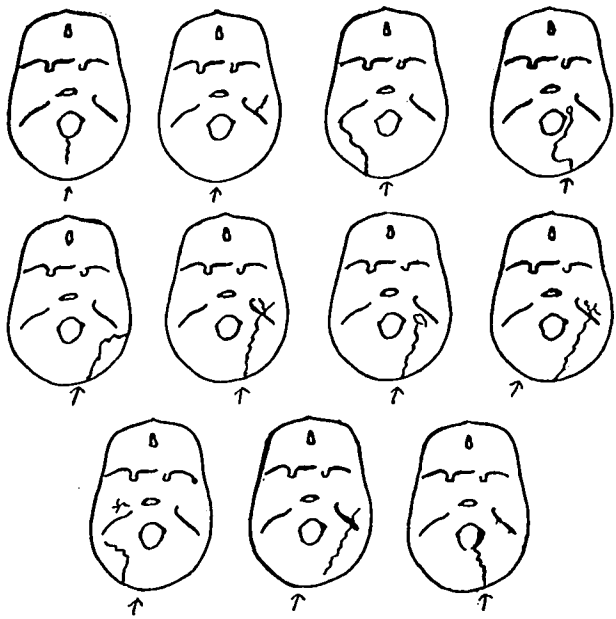

FIG. 11.—Lines of fracture resulting from occipital violence.

FIG. 12.—Lines of fracture resulting from violence of unknown direction.

The optic foramen was traversed in three out of the fourteen cases implicating the orbital fossa (21.4 per cent.), once on both sides. This does not quite justify the statement that the lesion is rare, but falls short of the frequency noted by Hoelder, who states that 50 per cent. of frontal fractures involve this foramen. Rawling's observation regarding the comparative immunity of the great vessels and the nerves of the base was borne out in a striking manner.

In one case all three fossæ were invaded on both sides, furnishing the second case of this lesion recorded as far as I am aware, the first being reported by Phelps (*New York Medical Journal*, January 14, 28, 1893).

The following are the diagrams grouped according to the estimated direction of the violence: (Figs. 6 to 12.)

The clinical records of hospital cases are less reliable than the pathological reports, unless we are sure that the observations regarding, for example, the pupils and the reflexes have been always made by those skilled in these branches; they offer much of interest, however, viewed with this reservation.

PUPILS.

The clinical records of these cases emphasized the fact that among the symptoms of basal fracture pupillary disturbance must be reckoned among the most constant and reliable, both for diagnosis and prognosis.

In the forty-four cases in which the condition of the pupils was noted, only thirteen were normal in size and reaction. The variety of the disturbance is illustrated by the fact that in seven cases both were small; in five, both large; in sixteen they were unequal (in three, one pupil contracted; in nine, one dilated; in one, both contracted, but unequally; in one, the left dilated and non-reacting, the right contracted and reacting; in two no note was made on this point); in three, the pupils were alike, but did not react to light. In a large number of these thirty-one cases it was noted that one or both pupils failed to react to light.

The importance of this point in prognosis is accentuated

by the observations of Lovett and Munro (*Medical and Surgical Records of Boston City Hospital,* 1889), who find that the pupils failed to react in thirty-nine out of fifty-three fatal cases of basal fracture in which they were recorded, whereas they failed to react in only one of twelve cases with recovery after the same diagnosis had been made and the pupils recorded. Similarly, Nichols (*idem.,* 1895) states that in fifty-four cases of head injury with non-reacting pupils, forty-seven died, and that in the twenty-four cases diagnosticated as basal fracture, *all were fatal,* from which he justly concludes that this is the most unfavorable single symptom.

Among the authorities laying special stress on the pupils, Phelps (*New York Medical Journal,* 1893) describes them as " variable, unsymmetrical, dilated, or contracted."

The disordered pupil is not susceptible of easy explanation; perhaps various factors take part. *The generally accepted paralysis of the third nerve causing dilatation of the pupil is untenable,* inasmuch as it is hardly credible that the ciliary fibres of this nerve should be so constantly affected without other sign of third nerve paralysis, to say nothing of the fact that the situation of this nerve in the wall of the cavernous sinus would naturally tend to protect it from injury.

The substitution of Rawling is hardly more acceptable. He attributes the disordered pupils to trauma affecting the cortical centre for contraction of the pupil, and states that the pupil is first contracted, then dilated.

One fact alone tends to eliminate cortical injury as playing a prominent part in the disordered pupils of basal fracture, namely, in most pupillary changes due to cortical influence, whether experimental or pathological, the alteration is bilateral and accompanied by other muscular phenomena as ptosis or conjugate deviation.

Doubtless various factors play a part in producing the altered pupils in this lesion, but *if disorder of any simple mechanism is to be credited with the production of the Hutchinson pupil or the other pupillary changes noted, the only lesion*

worthy of this place is disturbance, irritative or paralytic, of the intracranial fibres of the ciliospinal tract.

This tract after leaving the cervical sympathetic passes into the base with the carotid plexus, thence forward by the ophthalmic division of the fifth and its nasal branch, having first passed over the Gasserian ganglion. The fact is established that irritation of this tract causes dilatation, and its destruction contraction, of the pupil. The existence of dilator muscles in the iris seems to have been now fairly established (Langley and Anderson, Grenert, Devries, *et al.*). The fibres of the ciliospinal tract through which these muscles are presumably innervated would seem at least equally accessible with the third nerve to injury either from fracture of the base, or from uncomplicated middle meningeal hæmorrhage. In fact, I am inclined to think that at one point in their course they are peculiarly susceptible to injury, namely, at the apex of the petrous bone, in the region where the force transmitted along this buttress is suddenly interrupted and deadened by the buttress coming to an end. Nor is this tract open to the objection that other than pupillary symptoms should follow its disturbance, for the only other symptoms to be expected would be those of vasomotor disorder; such symptoms are by no means wanting, though they have lacked special study.

The proposition that initial contraction precedes dilatation can hardly be regarded as established. The following case which came under my observation within fifteen minutes of the accident would certainly point towards dilatation as a primary symptom.

CASE.—A teamster fell from his wagon, striking violently upon the back of the head. The accident occurred at six P.M., near the Massachusetts General Hospital, and he was brought immediately to the accident-room, where I saw him. There was extensive tear of the scalp in the occipital region. The patient was partially conscious, though unable to answer questions coherently; he was restless and combative, apparently alcoholic.

The left pupil was widely dilated and did not react to light. The right was normal. The epigastric, abdominal, patellar, and

plantar reflexes were wanting on both sides; there was no Babinski. The cremaster reflex was present and lively.

He was admitted to the House in Dr. Cabot's service, where I saw him again the next morning at nine o'clock. The pupils were then practically alike, and the left as well as the right reacted perfectly to light. All the reflexes had returned and had become active.

There was no bleeding from ears or nose, no subconjunctival hæmorrhage, no ecchymoses of lids or other region. The patient was kept under careful observation for three days, when he was allowed to go home. No further cerebral symptoms have appeared.

In casting about for an explanation of the dilatation and immobility of the pupil in this case, we must assume a unilateral and definitely localized, though temporary, injury. To me none seems more plausible than irritation by injury of the ciliospinal fibres on one side.

We may well leave this question still open when we realize the maze of uncertainty regarding even the course of the fibres, and the situation of the centres, constituting the primary reflex arc, as recently exhaustively reviewed by Thomas (*American Journal of the Medical Sciences*, December, 1903).

REFLEXES.

In the twenty-seven cases in which the condition of the knee-jerk was specified, it was stated to be normal in twelve, increased in seven, diminished in two, and wanting in six; in one case it was noted as still absent at the end of five days. In one case, definitely spastic, at the first examination the knee-jerks were exaggerated and the Babinski sign was present. The cremaster reflex was noted in two cases only, present in both. In three cases the general statement, "reflexes absent," appeared, without specifying the reflexes tested. This was an unfortunate omission, for the condition of the cremaster reflex would have been of interest in view of the exemption of this reflex from the general loss in the case of concussion and con-

tusion above cited. Further observations on this point are desirable.

Whatever lesson is to be drawn from the reflexes in these cases, it should not be regarded as specially diagnostic of basal fracture, but as resulting from violent jarring of the intracranial contents, accompanied perhaps by local bruising and by hæmorrhage, either limited or extensive.

The number of observations was small, but the proportion of cases in which the direction was towards lessening or loss was noteworthy. Doubtless some, at least, of the cases of exaggerated reflex represented a secondary condition; indeed, I suspect that in every instance the first result of a violent jar is a tendency towards lessening or loss of reflexes, even though sometimes speedily followed by their return and under certain circumstances by their intensification. The case of concussion and contusion above cited certainly shows that the reflexes (excepting the cremaster) may be wanting immediately after cerebral trauma, only to become extremely active within a few hours.

To attribute the lessened reflexes to shock of the spinal cord seems hardly satisfactory. In fact, if all the reflexes have their controlling mechanism in the cord, it is hard to see why the cremaster reflex should remain active while the rest are abolished. In case it proves that the cremaster usually escapes, it would seem to me far more probable that, while the mechanism controlling the cremaster reflex may have remained purely spinal, those controlling the other reflexes have passed cerebralwards in the higher development of the nervous system, as advocated by Grasset and others, though it seems probable that there is no single centre for the reflexes. Perhaps, as my colleague Dr. Paul has suggested, individuals are divided into those with predominating spinal reflex control, and those with predominating cerebral element, just as they are separated into visuels and auditifs on the sensory side of the language mechanism.

The exaggeration of reflexes is not so easy of explanation under Grasset's supposition; perhaps in some cases, as after

simple concussion, the reaction brings about an exalted irritability of the cerebral mechanism after recovery from the paralyzing effect of the trauma, or perhaps again, as I have suggested in connection with the exaggerated reflexes of chronic spastic paralysis, the lower spinal centres are ready to take up their latent function, and this even in an exaggerated manner when freed from cerebral control, especially under the stimulus of irritation, as by hæmorrhage, of the pyramidal fibres.

THE RELATION OF PROFUSE AND CONTINUED BLEEDING FROM THE EAR TO MIDDLE MENINGEAL HÆMORRHAGE.

The views of Rawling on this question are of sufficient practical bearing to justify careful analysis, and this I have made on the cases at hand with the following result. Bleeding from one or both ears was noted in twenty-one cases (in marked contrast to the ninety cases of Graf (*Deutsche Zeit. f. Chir.*, Band lxviii, p. 464) in which it appeared in seventy-seven instances). In most of the cases in which bleeding from the ear was noted, it seems to have been temporary and small in quantity. In three cases it was described as profuse, and in one case as persistent. *In none of these four cases was middle meningeal hæmorrhage found on autopsy;* nor, indeed, evidence of rupture of any of the large vessels, either arterial or venous; conversely, *middle meningeal hæmorrhage was found in nine cases, in eight without bleeding from the ear, in one with slight bleeding.*

RECAPITULATION.

1. In the majority of the cases the basal fracture resulted from impact received in the horizontal plane of the skull, whether upon the frontal or the occipital region or upon the side of the head.

2. While certain of the basal fractures extended from the vertex, there was no suggestion of the *contre-coup* of earlier writers.

3. The line of fracture tended to enter the fossa nearest the point of impact, and to extend in the general direction in which force was applied.

4. The lines of fracture in traversing the base tended to follow lines of least resistance, and in twenty-two of the fifty cases these lines corresponded more or less accurately to those indicated by Rawling, but the exceptions were too marked and too constant to allow the establishment of fixed rules.

5. The sella Turcica was implicated in 36 per cent. of the fractures. The petro-occipital and masto-occipital sutures furnished common lines of least resistance. Fractures extending across the base tended to run parallel to the petrous portion of the temporal bone and through the sella Turcica. Certain blows on the occiput tended to cause a line of fracture extending to the jugular foramen or across the petrous bone. The portion of the petrous bone containing the auditory apparatus showed itself peculiarly liable to fracture, more often transversely than longitudinally.

6. In seven cases (14 per cent.) the fracture was limited to the base after vault impact in the horizontal plane. Neither Rawling's theory of transmitted force nor the theory of bursting fracture of von Wahl and others suffices alone to explain these cases. The results of experiments with bodies of simpler structure would suggest that the bursting principle predominates in pure compression of the skull, and the principle of transmitted force in case of blows, while both play important parts in case of falls.

7. The orbital foramen was implicated in 21.4 per cent. of the cases of orbital fossa fracture.

8. Inequality and immobility of pupils, or both, furnish the most frequent and unfavorable sign of fracture of the base. In the forty-four cases in which the pupils were recorded, they were normal in only thirteen.

9. Injury to the ciliospinal tract in its intracranial course is a more probable cause of the Hutchinson pupil and the other pupillary changes than injury to the third nerve or to the cortex, though no single lesion explains all cases.

10. The reflexes may be lessened or lost in fracture of the base, as in any case of violent jarring of the brain. On the other hand, they may be increased even to spasticity, probably through direct pressure on the pyramidal tract as by hæmorrhage. It is probable that the initial result of the impact in all cases is a tendency towards lessening or loss of the reflexes.

11. Profuse and persistent bleeding from the ear does not suggest middle meningeal hæmorrhage. No middle meningeal hæmorrhage was found in the cases of profuse and persistent bleeding, and, conversely, hæmorrhage from this artery occurred eight times without, and once with only slight, bleeding from the ear.